

# MAGNETIC SUSCEPTIBILITY – MSL

## Introduction

Magnetic susceptibility is the degree to which a material can be magnetized in an external magnetic field. Magnetic susceptibility is used mostly as a relative indicator for changes in composition due to its high sensitivity to iron-bearing minerals. These changes can be linked to paleoclimate-controlled depositional processes. The high precision and sensitivity of susceptibility loggers makes this measurement extremely useful for core-to-core and core-to-downhole log correlations.

Early in the ODP (Ocean Drilling Program), magnetic susceptibility measurements were taken with a manually-controlled susceptibility meter, so measurements on whole-core or archive halves were usually limited. MSL (magnetic susceptibility logger) was integrated into the MST to measure the susceptibility of the whole-round core sections which significantly increased the number and density of measurements. Later in the ODP, a split-core track was built to measure point susceptibilities with a Bartington magnetic susceptibility probe.

## Data Acquisition

Magnetic susceptibility measurements have been taken throughout ODP, starting from Leg 101. Details about changes to the magnetic susceptibility data acquisition system are sketchy. During Leg 101, a Bartington Instruments MS1 susceptibility meter had a discrete point susceptibility sensor and a 100 mm pass-through susceptibility loop. By Leg 115, the MS1 was using an 80 mm pass-through loop with an operating frequency of 0.465 kHz. The MS1 was integrated into the MST during Leg 124 and became known as MSL. The Bartington Instruments MS2C system was installed as part of the MST upgrade during Leg 169. The 80 mm loop had an operating frequency of 0.565 kHz and an alternating field intensity of 80 A/m (=0.1 mT). Table 1 below briefly summarizes known changes to the magnetic susceptibility data acquisition systems.

The Bartington instrument output values are relative, volume-specific susceptibilities which must be corrected before they can be reported as absolute susceptibilities. However, no calibration or correction was implemented to volume correct the raw susceptibility values. Bulk susceptibility values were collected and reported in SI units but should be considered dimensionless.

## Standard Operating Procedures

Prior to Leg 131, there is little information about data collection procedures for magnetic susceptibility. The cores were stored on a rack to allow them to equilibrate to room temperature, because MSL measurements are sensitive to temperature. Starting around Leg 163, drift correction was implemented. Instrument drift may occur during

the period of a section scan (usually about 10 minutes). Assuming that drift was linear over the time of interest, the Bartington instrument was zeroed at the beginning of each run, and a zero-background measurement taken at the end. Using the elapsed time information collected at each analysis location, the susceptibility value can be drift corrected.

More complete information about ODP Magnetic Susceptibility measurements can be found in *Technical Note 26: Physical Properties Handbook*, Chapter 4.

Table 1: MSL data acquisition system

<b>Legs</b>	<b>Equipment</b>	<b>Comments</b>
101 – 114	MS1 – 100 mm loop	Data collected under Bartington instrument control?
115 – 124	MS1 – 80 mm loop	Data collected under Bartington instrument control?
124 – 130	MS1 – 80 mm loop	Initial installation of MST with GRA, PWL and MSL. Not all software compatible with shipboard environment but system operational.
131 – 133 (Site 817)	MST Track - MS1 – 80 mm loop	Software upgrade? Data no longer stored in S1032. MS value in SI units, probably not volume-corrected.
133 (Site 818) – 150	MST Track - MS1 – 80 mm loop	Leg 133 - Major software upgrade. Other minor software changes, data file format changes ; Leg 149 – NGR added to track.
151 – 162	MST Track - MS1 – 80 mm loop	Leg 151 – Major software upgrade
163 – 169 (Site 1036)	MST Track - MS1 – 80 mm loop	Major software upgrade installed Leg 163 Port Call. Elapsed time data for drift correction saved.
169 (Site 1037) – 187	MST Track – MS2C – 80 mm loop	Hardware and software upgrade. Leg 171 Janus database operational.
188 – 210	MST Track – MS2C – 80 mm loop	Minor software changes during this time.

## MSL Archive

### Pre-Janus Archive

Whole-core magnetic susceptibility data were collected digitally using computer data acquisition programs except for discrete measurements made before Leg 108. For data collected through Leg 130, the data were uploaded to an S1032 database. The discrete measurements made before Leg 108 were collected on paper forms and encoded on shore. Beginning with Leg 131, the raw data files were saved and returned to ODP/TAMU for archival on the ODP data servers.

### Migration of MSL data to Janus

The data model for MSL magnetic susceptibility can be found in Appendix I. Included are the relational diagram and list of the tables that contain data pertinent to MSL, the column names and the definition of each column attribute. ODP Information Services Database Group was responsible for the migration of pre-Leg 171 data to Janus. The

migration of these data was done in conjunction with the other MST datasets – GRA, PWL and NGR. Each change in format was documented and added to the MST Migration program. Additional information about the migration of PWL data or original file formats can be requested from the IODP Data Librarian.

### Janus MSL Data Format.

The MSL data can be retrieved from JanusWeb using a predefined query. The MSL Magnetic Susceptibility query webpage allows the user to extract data using the following variables to restrict the amount of data retrieved: leg, site, hole, core, section, specific run numbers, depth range, or latitude and longitude range. In addition, the user can use the Output Raw Data option in the query to extract the raw measurements and data acquisition parameters. Because there are over 4.7 million MSL data records in Janus, a user must restrict the amount of data requested.

The following table lists the data fields retrieved from the Janus database for the predefined MSL query with Output Raw Data option turned on. The first column contains the data item; the second column indicates the Janus table or tables in which the data were stored; the third column is the Janus column name or the calculation used to produce the value. Appendix II contains additional information about the fields retrieved using the Janus Web MSL query, and the data format for the archived ASCII files.

Table 2. MSL Magnetic Susceptibility query with Output Raw Data option

Item Name	Janus Table	Janus Column Name and Calculation
Leg	SECTION	Leg
Site	SECTION	Site
Hole	SECTION	Hole
Core	SECTION	Core
Type	SECTION	Core_type
Section	SECTION	Section_number
Top (cm)	MSL_SECTION_DATA	MST_Top_Interval x 100
Depth (mbsf)	DEPTH_MAP, MSL_SECTION_DATA	DEPTH_MAP.Map_Interval_Top + MSL_SECTION_DATA.MST_Top_Interval
Magnetic Suscept. (inst.units)	MSL_SECTION_DATA	Meas_susceptibility_mean [in instrument units]
Drift-Corrected Suscept. (inst. units)	MSL_SECTION_DATA	Meas_susceptibility_mean – (Bkgd_susceptibility * sample_elapsed_zero_time / bkgd_elapsed_zero_time) [in instrument units]
Run Number	MSL_SECTION	Run_Number
Run Date/Time	MSL_SECTION	Run_Date_Time (dd-mon-yy hh:mm)
Core Status	MSL_SECTION	Core_Status
Liner Status	MSL_SECTION	Liner_Status
Requested Interval	MSL_SECTION	Requested_DAQ_Interval
Data Acquisitions per Sample	MSL_SECTION	Req_DAQs_per_sample
Background Suscept.	MSL_SECTION	Bkgd_susceptibility
Background Time	MSL_SECTION	bkgd_elapsed_zero_time
Core Temp.	MSL_SECTION	Core_temperature
Loop Temp.	MSL_SECTION	Loop_temperature
Elapsed Time	MSL_SECTION_DATA	Sample_elapsed_zero_time
Actual Period (s)	MSL_SECTION_DATA	Actual_DAQ_period
Core Diameter (cm)	MSL_SECTION_DATA	Core_diameter

## Data Quality

There are several things that can affect the quality of MSL data. One of the most significant factors for magnetic susceptibility measurements is contamination of the cores by metal fragments. Metal shards come from drill bits, fittings and rusty drill pipe (Sager, W.W., 1986). The nature of drilling makes it very difficult to totally eliminate this problem. Drilling method and type of cored material also have a major affect. Undisturbed sediments with no drilling disruption or voids will typically give the highest quality measurements.

Because of the lack of a calibration procedure for the MSL system, there can be equipment problems that are not immediately identified. For example, during Leg 130 three different susceptibility loops with different diameters and frequencies were used. Data from Site 803 were collected with an 80 mm loop with a frequency of 0.47 kHz. The Site 803 data show some excessive drift as this loop was not working properly. At Site 804 Hole A Core 3H-1 a change was made to a 100 mm loop with a frequency of 0.86 kHz. The loop was changed again to an 80 mm loop with a frequency of 0.565 kHz at Site 806 Hole B Core 26H. This loop was used until the end of the cruise. The susceptibilities from the 3 different loops are different and not directly comparable.

The core sections were run through the MST system before the liners were opened and the core curated. During the curation process, core material was often shifted. In sedimentary cores, voids may have been closed. Gassy cores may have small voids that continue to enlarge after analysis. Sections may not be completely full, and material may have spread throughout the liner. After curation, this material was shoved up to close voids and the section's curated length was less than what was originally analyzed. The effects can be seen when looking at the data for a section though they are not necessarily as dramatic as GRA or PWL: 1) there are reasonable susceptibility values beyond the curated length of the section (null depth values); 2) there are zero or negative susceptibility values within the section indicating the measurement interval could be within a void or have less than a full liner.

Hard rock cores can be continuous cylinders with a uniform diameter or can be broken into small irregular pieces. The curation process shifts hard rock pieces, sometimes even shifting core material from its original liner section to an adjacent section liner. Where the core material was in its liner during analysis and where it was eventually placed after curation can be very different. MSL data for these types of cores should be used with caution.

Table 3: MSL Analysis Statistics

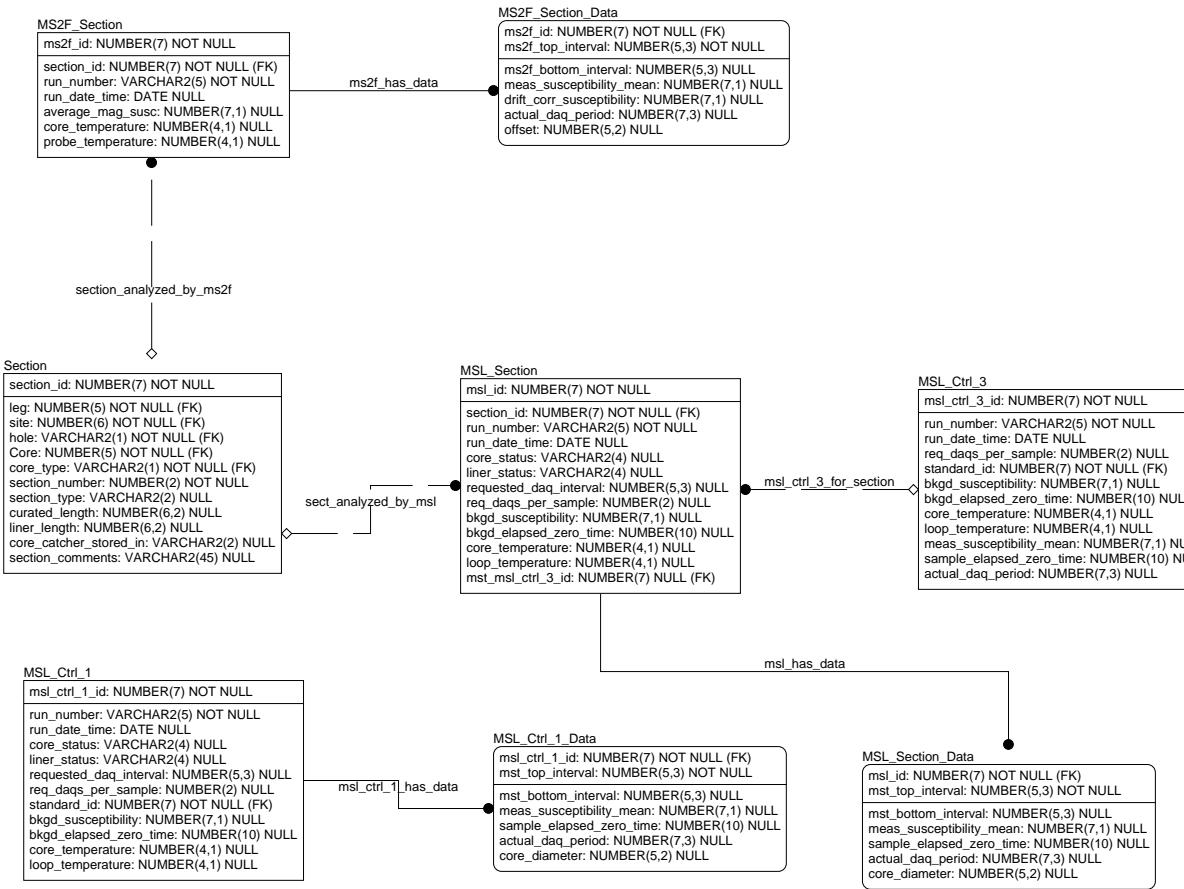
	<b>Core Recovery</b>	<b>MSL Analyzed</b>	<b>Percent</b>
<b>APC – coretype H</b>	113,999 meters	98,462 meters	86.4 %
<b>XCB – coretype X</b>	61,638 meters	50,635 meters	82.1 %
<b>RCB – coretype R</b>	45,869 meters	37,688 meters	82.2 %
<b>TOTAL</b>	222,429 meters	186,984 meters	84.1 %

One more important factor that needs to be considered is operator error. Throughout the ODP, the operator manually entered core information into the data acquisition program. Typographical errors or entering the wrong information occasionally happened, and some mistakes were not identified. Sometimes, the scientific party noticed the error and corrected it for the data included in the Initial Report volume, but the original files did not get corrected. A lot of effort during verification of the migrated MSL data has gone into finding sections that may have been misidentified. Some runs have been renamed to different sections. The evidence for misidentification had to be conclusive. Listed below are some of the clues used to find incorrectly identified analyses:

- two runs for a given section, no run for the following section;
- run numbers out of sequence;
- two runs for a section, run numbers out of sequence - no data for that core and section in a different hole, but sequence of run numbers would be correct;
- Nature of the core material – length of core, voids or less than full liners.

## References

- Blum, P., 1997, Physical Properties Handbook: A guide to the shipboard measurement of physical properties of deep-sea cores, ODP Tech. Note 26.
- Sager, W.W., 1986, Magnetic Susceptibility Measurements of Metal Contaminants in ODP Leg 101 Cores. In Austin, J.A., Jr., Schlager, W., Palmer, A.A., et al., *Proc. ODP, Init. Repts*, 101: College Station, TX (Ocean Drilling Program), 39-43.



## APPENDIX I: Janus Data Model – MSL – Magnetic Susceptibility

Magnetic Susceptibility Logger - MSL		
Table Name	Column Name	Column Comment
<b>MSL_Section</b>	msl_id	Unique Oracle-generated sequence number for each MSL analysis run.
	section_id	Unique Oracle-generated sequence number to identify each section.
	run_number	Number identifying a run generated by the data acquisition software. This number is not used to identify the run in Janus because it may not be unique.
	run_date_time	Timestamp when analysis was run.
	core_status	Indicates if a full or half (split) core is being analyzed. Valid values are FULL or HALF.
	liner_status	Records if a core liner was used, a split liner or no liner. Valid values are FULL, HALF and NONE.
	requested_daq_interval	Data acquisition interval requested for section analysis, in centimeters.
	req_daqs_per_sample	Requested number of data acquisitions taken per sample interval.
	bkgd_susceptibility	A measurement of the background susceptibility associated with a core section analysis.
	bkgd_elapsed_zero_time	Time when zero-background measurement taken, for drift correction.
	core_temperature	Temperature of the core in °C.
	loop_temperature	Temperature of a susceptibility loop in °C.
	mst_msl_ctrl_3_id	Unique Oracle-generated sequence identifier for MSL control-1 run, nullable.

<b>MSL_Section_Data</b>	msl_id	Unique Oracle-generated sequence number for each MSL analysis run.
	mst_top_interval	The top interval of a measurement in meters measured from the top of a section.
	mst_bottom_interval	The bottom interval of a measurement in meters measured from the top of a section.
	meas_susceptibility_mean	The measured susceptibility value in unitless volume susceptibility.
	sample_elapsed_zero_time	Elapsed time since background measurement (for drift correction).
	actual_daq_period	Actual data acquisition period used for measurements, in seconds.
	core_diameter	Diameter of core, in centimeters.

<b>MSL_Ctrl_1</b>	msl_ctrl_1_id	Unique Oracle-generated sequence identifier for MSL control-1 runs, used to compare a sample run to a control-1 run.
	run_number	Number identifying a run generated by the data acquisition software. This number is not used to identify the run in Janus because it may not be unique.
	run_date_time	Timestamp when analysis was run.
	core_status	Indicates whether a whole or half (split) core is being analyzed. Valid values are FULL or HALF.
	liner_status	Records if a core liner was used, a split liner or no liner. Valid values are FULL, HALF and NONE.
	requested_daq_interval	The data acquisition interval requested for section analysis, in centimeters.
	req_daqs_per_sample	The requested number of data measurements taken per sample interval.
	standard_id	Identifier for a physical properties standard.
	bkgd_susceptibility	A measurement of the background susceptibility associated with a sample measurement.
	bkgd_elapsed_zero_time	Time when zero-background measurement taken, for drift correction.
	core_temperature	Temperature of the core in °C.
	loop_temperature	Temperature of a susceptibility loop in °C.

<b>MSL_Ctrl_1_Data</b>	msl_ctrl_1_id	Unique Oracle-generated sequence identifier for MSL control-1 runs, used to compare a sample run to a control-1 run.
	mst_top_interval	The top interval of a measurement in meters measured from the top of a section.
	mst_bottom_interval	The bottom interval of a measurement in meters measured from the top of a section.
	meas_susceptibility_mean	The measured susceptibility value in unitless volume susceptibility.
	sample_elapsed_zero_time	Elapsed time for measurement (for drift correction).
	actual_daq_period	The actual data acquisition period used for measurements, in seconds.

<b>Magnetic Susceptibility Logger - MSL</b>		
<b>Table Name</b>	<b>Column Name</b>	<b>Column Comment</b>
	core_diameter	Diameter of core, in centimeters.
<b>MSL_Ctrl_3</b>	msl_ctrl_3_id	Unique Oracle generated sequence identifier for MSL control-3 runs.
	run_number	Number identifying a run generated by the data acquisition software. This number is not used to identify the run in Janus because it may not be unique.
	run_date_time	Timestamp when analysis was run.
	req_daqs_per_sample	Requested number of data acquisitions taken per sample interval.
	standard_id	Identifier for a physical properties standard.
	bkgd_susceptibility	A measurement of the background susceptibility associated with a sample measurement.
	bkgd_elapsed_zero_time	Time when zero-background measurement taken, for drift correction.
	core_temperature	Temperature of the core in °C.
	loop_temperature	Temperature of a susceptibility loop in °C.
	meas_susceptibility_mean	The measured susceptibility value in unitless volume susceptibility.
	sample_elapsed_zero_time	Elapsed time for measurement (for drift correction).
	actual_daq_period	Actual data acquisition period used for measurements, in seconds.
<b>Section</b>	section_id	Unique Oracle-generated sequence number to identify each section. This is done because of the physical subsection / zero section problems. In adding new sections, deleting sections or changing sections - don't want to have to renumber.
	leg	Number identifying the cruise for which data were entered into the database.
	site	Number identifying the site from which the core was retrieved. A site is the position of a beacon around which holes are drilled.
	hole	Letter identifying the hole at a site from which a core was retrieved or data were collected.
	Core	Sequential numbers identifying the cores retrieved from a particular hole. Cores are generally 9.5 meters in length, and are numbered serially from the top of the hole downward.
	core_type	A letter code identifying the drill bit/coring method used to retrieve the core.
	section_number	Cores are cut into 1.5 m sections. Sections are numbered serially, with Section 1 at the top of the core.
	section_type	Used to differentiate sections of core (S) from core catchers (C). Previously core catchers were stored as section number CC, but in Janus core catchers are given the next sequential number from the last section recovered.
	curated_length	The length of the section core material, in meters. This may be different than the liner length for the same section. Hard rock cores will often have spacers added to prevent rock pieces from damaging each other.
	liner_length	The original length of core material in the section, in meters. Sum of liner lengths of all the sections of a core equals core recovery.
	core_catcher_stored_in	Sometimes the core catcher is stored in a D tube with a section. core_catcher_stored_in contains the section number of the D tube that holds the core catcher.
	section_comments	Comments about this section.

Appendix II: Description of data items from MSL query.

<b>Column Name</b>	<b>Column Description</b>	<b>Format</b>
Leg	Number identifying the cruise. The ODP started numbering the scientific cruises of the <i>JR</i> at Leg 101. A leg was nominally two months duration. During the 18+ years of the ODP, there were 110 cruises on the <i>JR</i> .	Integer 3
Site	Number identifying the site. A site is the location where one or more holes were drilled while the ship was positioned over a single acoustic beacon. The <i>JR</i> visited 656 unique sites during the course of the ODP. Some sites were visited multiple times, including some sites originally visited during the Deep Sea Drilling Program for a total of 673 site visits.	Integer 4
Hole	Letter identifying the hole. Multiple holes could be drilled at a single site by pulling the drill pipe above the seafloor, moving the ship some distance away and drilling another hole. The first hole was designated 'A' and additional holes proceeded alphabetically at a given site. Location information for the cruise was determined by hole latitude and longitude. During ODP, there were 1818 holes drilled or deepened.	Text 1
Core	Cores are numbered serially from the top of the hole downward. Cored intervals are up to 9.7 m long, the maximum length of the core barrel. Recovered material was placed at the top of the cored interval, even when recovery was less than 100%. More than 220 km of core were recovered by the ODP.	Integer 3
Type	All cores are tagged by a letter code that identifies the coring method used.	Text 1
Section	Cores are cut into 1.5 m sections in order to make them easier to handle. Sections are numbered serially, with Section 1 at the top of the core. MSL measurements were made on sections. Core Catcher sections identified as "CC".	Integer 2 (Text 2)
Top (cm)	The top interval of a measurement in centimeters measured from the top of a section.	Decimal F4.1
Depth (mbsf)	Distance in meters from the seafloor to the measurement location.	Decimal F7.3
Magnetic Suscept. (inst.units)	The measured susceptibility value (instrument units, SI).	Decimal F7.1
Drift-Corrected Suscept. (inst. units)	The measured susceptibility value with background drift correction (instrument units, SI).	Decimal F8.2
Run Number	Number generated by the data acquisition software, to identify an analysis run of a section of core.	Text 5
Run Date/Time	Timestamp identifying when analysis was run.	Text 16 (yyyy-mm-dd hh:mi)
Core Status	Indicates whether a whole or half (split) core is being analyzed. Valid values are FULL or HALF.	Text 4
Liner Status	Records if a core liner was used, a split liner or no liner. Valid values are FULL, HALF and NONE.	Text 4
Requested Interval	Requested sampling interval in centimeters.	Decimal F5.3
Data Acquisitions per Sample	Requested number of measurements at each interval.	Integer 2

<b>Column Name</b>	<b>Column Description</b>	<b>Format</b>
Background Suscept.	A measurement of the background susceptibility associated with a core section analysis.	Decimal F7.1
Background Time	Time when zero-background measurement taken, for drift correction.	Integer 10
Core Temp.	Temperature of the core in °C.	Decimal F4.1
Loop Temp.	Temperature of a susceptibility loop in °C.	Decimal F4.1
Elapsed Time	Elapsed time since background measurement (for drift correction).	Integer 10
Actual Period (s)	Actual data acquisition period used for measurements, in seconds.	Decimal F7.3
Core Diameter (cm)	Diameter of core in centimeters.	Decimal F5.2